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# Technology Opportunity

Technology Transfer & Partnership Office

TOP3-00186

## Measurement of Gas Flow Velocity and Thermodynamic Properties Using Molecular Rayleigh Scattering

### Technology

The National Aeronautics and Space Administration (NASA) seeks to transfer technology for the development of a gas flow measurement system utilizing the principles of molecular Rayleigh scattering. This nonintrusive optical point-wise measurement technique is useful for obtaining time-averaged information about gas velocity, temperature, density, and turbulence intensity, or dynamic information about gas velocity and density in unseeded flows.

### Benefits

- This technique can be used for flow measurements in turbulent flows over a wide range of flow speeds from zero to supersonic
- Does not require seeding the flow with particles and is nonintrusive to the flow
- Allows simultaneous measurement of velocity and thermodynamic flow properties
- Dynamic measurements have been demonstrated up to 100 kHz sampling rate

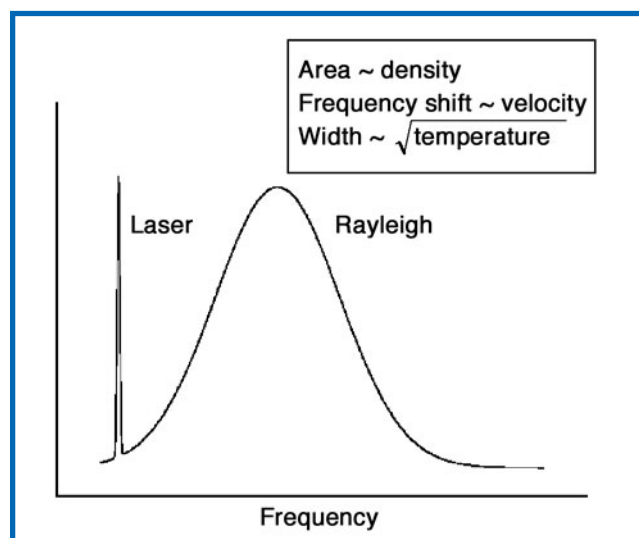


Figure 1.—Rayleigh scattering spectrum.

### Commercial Applications

- Flow studies for aeronautics and aerospace applications
- Gas leak detection
- Flow characterization in HVAC or convective cooling applications
- Wind tunnel measurements

### Technology Description

Molecular Rayleigh scattering is the result of elastic light scattering from gas molecules. When light from a single-frequency laser beam passes through a gas, the frequency of the scattered light is equal to the frequency of the incident laser light altered by the Doppler effect due to the motion of the molecules. The optical frequency spectrum of Rayleigh scattered light contains information about the gas density, bulk velocity, and temperature. Figure 1 shows a Rayleigh scattering spectrum containing the narrow laser line and the broadened Rayleigh spectral peak. If the gas composition is known, the total intensity of the Rayleigh spectrum is directly proportional to the gas density. The Doppler shift between the laser peak and the Rayleigh peak is proportional to the bulk flow velocity. The width of the Rayleigh spectrum is related to the gas temperature.

Based on the principles of Rayleigh scattering, a flow diagnostic has been developed to measure density, velocity, turbulence intensity, and temperature in subsonic and supersonic gas flows. The spectra of the laser light and the Rayleigh scattered light are analyzed using a Fabry-Perot interferometer (fig. 2) operated in the static imaging mode. The resulting circular fringe pattern contains spectral information about the light. Figure 3 shows sample fringe patterns for narrow line width laser light (left) and Rayleigh scattered light (right). The Rayleigh fringe is thermally broadened and shifted radially from the laser fringe by the Doppler shift associated with the gas velocity.

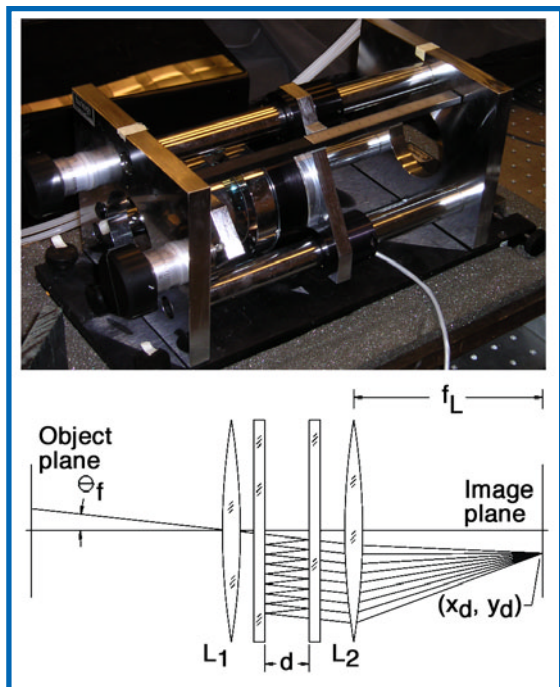


Figure 2. —Fabry-Perot interferometer.

For time-average measurements, the resulting fringe pattern is recorded using a low-noise charge-coupled device (CCD) camera. Nonlinear least squares analysis of the fringe pattern using a kinetic theory model of the Rayleigh scattered light provides estimates of density, velocity, temperature, and turbulence intensity of the gas flow averaged over the integration time of the camera.

For dynamic measurements, the camera system is replaced by a detection system consisting of three photomultiplier tubes (PMTs) operated in the photo-counting mode and sampled at rates up to 100 kHz. One PMT measures the total intensity of the collected scattered light to provide dynamic density information. The fringe pattern generated from the Rayleigh scattered light passing through the Fabry-Perot interferometer is split into inner and outer regions using a set of concentric mirrors. The intensity of the light in the inner and outer regions of the fringe are monitored using the other two PMTs. The ratio

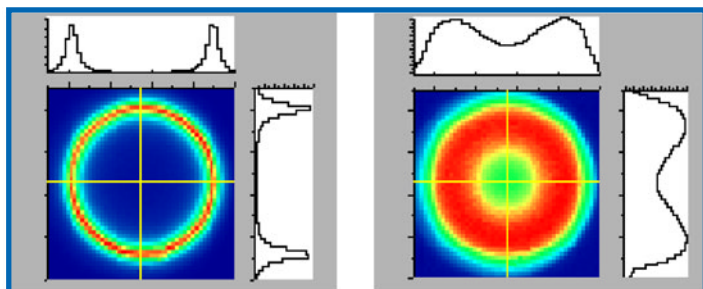


Figure 3. —Sample fringe patterns for narrow line width laser light (left) and Rayleigh scattered light (right).

of the intensities provides a measure of the flow velocity since the ratio changes as the fringe diameter increases or decreases. We are planning to extend the dynamic technique to allow for temperature measurement by increasing the spatial sampling resolution so that information about the width of the spectrum is available.

The data obtained from these measurements is useful for validation of computational fluid dynamics (CFD) codes. Dynamic measurements allow the calculation of power spectra for the various flow properties. This type of information is currently being used in jet noise studies, correlating sound pressure fluctuations with velocity and density fluctuations to determine noise sources in jets (Quiet Aircraft Technology Project). This nonintrusive technique is particularly useful in supersonic flows where seeding the flow with particles is not an option, and where the environment is too harsh for hotwire measurements.

## Options for Commercialization

NASA Glenn Research Center is interested in working with industry and academia to further develop this instrumentation technology and develop new applications for this novel technique.

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## References

Mielke, A.F.; Seasholtz, R.G.; Elam, K.A.; and Panda, J.: "Time-Average Molecular Rayleigh Scattering Technique for Measurement of Velocity, Density, Temperature, and Turbulence Intensity in High Speed Nozzle Flows." AIAA Paper 2004-0706, 2004.

## Key Words

Rayleigh scattering  
Light scattering  
Supersonic flow  
Turbulent flow  
Nonintrusive flow property measurement